References

1. JSC-07700, Volume XIV, "Space Shuttle System Payload Accommodations," Revision A, July 1982.

2. Hamilton, D. A., and Wade, D. C., "STS Payload Design Load Evolution," International Spacecraft Structures and Mechanical Testing Conference, Noordwijk, Holland, October 1988.

3. SP-T-0023B, "Specification Environmental Acceptance Testing," Johnson Space Center, September 1975.

4. NSTS-14046, "Payload Verification Requirements," Revision B, February 1988.

Appendix A - STS/Payload Bay Random Vibration and Acoustic Levels

This document presents design load factors which are intended to ensure flight safety from a structural standpoint. Some developers of electronic packages or other components may wish to conduct random vibration and/or acoustic testing to insure functionality. The STS payload bay random vibration levels for both longeron mounted and sidewall mounted payloads are presented here along with payload bay acoustic levels. This data is from JSC-07700, Vol XIV, "The Shuttle System Payload Accommodations." It should be noted that payload and experiment developers often use vibration levels which are based on their own experience and these levels are generally higher than those defined at Orbiter interfaces.

A1 - Acoustics. The acoustic levels in an empty cargo bay that are defined in Table A1 represent the minimum level to which a payload must be certified to be considered safe to fly on the STS. The acoustic levels during entry and landing are significantly below the ascent levels and shall be assumed negligible. Acoustic levels for specific payloads are dependent on payload geometry, surface area and acoustic absorption characteristics.

A2 - Random Vibration for Trunnion Mounted Payloads. The random vibration environments for the longeron trunnion and keel trunnion interfaces are specified in Tables A 2.1 and A 2.2. The longeron trunnion and keel trunnion criteria corresponds to vibration levels associated with the liftoff event.

A3 - Random Vibration for Longeron/Adapter Mounted Payloads. The random vibration environments for hardware mounted on the Orbiter payload bay longeron through an adapter, such as the APC, ICAPC, or GAS beam, is given in Table A 3.1.

A4 - Random Vibration for Crew Cabin Mounted Hardware. The random vibration environment for hardware mounted in the crew cabin is given in Table A.4.1.

Table A1 Orbiter Cargo Bay Internal Acoustics Environment

1/3 Octave Band Center Frequency (Hz)	Sound Pressure Level (dB) ref. 2X10^{-5} N/m^2 Lift-off 5 Seconds/Flight*	Aeronoise 10 Seconds/Flight*
31.5	122.0	112.0
40.0	124.0	114.0
50.0	125.5	116.0
63.0	127.0	118.0
80.0	128.0	120.0
100.0	128.5	121.0
125.0	129.0	122.5
160.0	129.0	123.5
200.0	128.5	124.5
250.0	127.0	125.0**
315.0	126.0	125.0**
400.0	125.0	124.0**
500.0	123.0	121.5
630.0	121.5	119.5
800.0	120.0	117.5
1000.0	117.5	116.0
1250.0	116.0	114.0
1600.0	114.0	112.5
2000.0	112.0	110.5
2500.0	110.0	108.5
Overall	138.0	133.5

* Time per flight does not include a scatter factor.

** NOTE: NARROW BAND DISCRETE NOISE IS RADIATED FROM THE CARGO BAY VENT DOORS DURING TRANSONIC/LOW SUPERSONIC FLIGHT.

8 SECONDS PER FLIGHT (WITHOUT SCATTER FACTOR)

One-Third Octave Band Center Frequencies, HZ	Sound Power Level dB Ref. 10^{-12} Watts
250	128
315	136
400	130

Table A2.1 Orbiter Cargo Bay Random Vibration
Payload Longeron Trunnion/Orbiter Interface

o X Axis	20 to 58 HZ	.0025 G^2/HZ
	58 to 125 HZ	+9 dB/OCT
	125 to 300 HZ	.025 G^2/HZ
	300 to 900 HZ	-9 dB/OCT
	900 to 2000 HZ	.001 G^2/HZ
	OVERALL = 3.1 GRMS	
o Y Axis	20 to 68 HZ	.004 G^2/HZ
	68 to 125 HZ	+9 dB/OCT
	125 to 300 HZ	.025 G^2/HZ
	300 to 900 HZ	-9 db/OCT
	900 to 2000 HZ	.001 G^2/HZ
	OVERALL = 3.1 GRMS	
o Z Axis	20 to 45 HZ	.009 G^2/HZ
	45 to 125 HZ	+3 dB/OCT
	125 to 300 HZ	.025 G^2/HZ
	300 to 900 HZ	-9dB/Oct
	900 to 2000 HZ	.001 G^2/HZ
	OVERALL = 3.2 GRMS	

The associated time duration is 20 seconds per axis per flight which includes a fatigue scatter factor of 4.

Table A2.2 Orbiter Cargo Bay Random Vibration
Payload Keel Trunnion/Orbiter Interface

o X Axis	20 to 90 HZ	.008 G^2/HZ
	90 to 100 HZ	+9 dB/OCT
	100 to 300 HZ	0.01 G^2/HZ
	300 to 650 HZ	-9 dB/OCT
	650 to 2000 HZ	.001 G^2/HZ
	OVERALL = 2.3 GRMS	
o Y Axis	20 to 90 HZ	.008 G^2/HZ
	90 to 100 HZ	+9 dB/OCT
	100 to 300 HZ	.01 G^2/HZ
	300 to 650 HZ	-9 dB/OCT
	650 to 2000 HZ	.001 G^2/HZ
	OVERALL = 2.3 GRMS	
o Z Axis	20 to 60 HZ	.0023 G^2/HZ
	60 to 100 HZ	+9 dB/OCT
	100 to 300 HZ	.01 G^2/HZ
	300 to 650 HZ	-9 db/OCT
	650 to 2000 HZ	.001 G^2/HZ
	OVERALL = 2.2 GRMS	

The associated time duration is 20 seconds per flight which includes a fatigue scatter factor of 4.

Table A3.1 Orbiter Cargo Bay Random Vibration
Payload Sidewall Adapters/Orbiter Interface

0 X Axis	20 to 32 HZ	.003 G^2/HZ
	32 to 100 HZ	+6 dB/OCT
	100 to 500 HZ	.03 G^2/HZ
	500 to 2000 HZ	-4 dB/OCT
	OVERALL = 5.5 GRMS	
o Y Axis	20 to 45 HZ	+10 dB/OCT
	40 to 600 HZ	.06 G^2/HZ
	600 to 2000 HZ	-6 dB/OCT
	OVERALL = 7.7 GRMS	
0 Z Axis	20 to 45 HZ	.009 G^2/HZ
	45 to 70 HZ	+12 dB/OCT
	70 to 600 HZ	.05 G^2/HZ
	600 to 2000	-6 dB/OCT
	OVERALL = 7.0 GRMS	

The associated time duration is 20 seconds per axis per flight which includes a scatter factor of 4.

Table A.4.1 Random Vibration for Crew Cabin Mounted Hardware

o All Axes	20 - 150 HZ	+6 dB/OCT
	150 - 1000 HZ	0.03 G^2/HZ
	1000 - 2000 HZ	-6 dB/OCT

OVERALL = 6.5 GRMS

The associated time duration is 18 seconds per flight which includes a scatter factor of 4.

Appendix B - Design Considerations

B1. The following comments relative to structural design were provided by P. D. Smith of the Structural Mechanics Branch.

1. Make the structure simple. Many aircraft/spacecraft designers get carried away by thinking exotic missions require exotic hardware, when in reality exotic missions succeed when simple structure is provided. Visualizing a "how would I design this at home" approach is sometimes helpful. Structural design is basically "connect the head bone to the neck bone, etc." Do not over do it.

2. Understand load paths. Just because all the structure touches does not mean a correct load path has been provided. Avoid the "maze" design. The method of load transfer must be understood e.g., in flanged sections carrying bending and shear the bending moment is transferred through the flanges and the shear is transferred through the webs. Keep webs connected to webs and flanges connected to flanges. Joints have been designed where flanged sections such as I beams have only the flanges spliced, which weakens an otherwise adequate structure. Keep the load path to the reaction short and as straight as possible. Avoid, if possible, designs involving possible instabilities. If torsion of individual members is involved, use closed sections or at least symmetrical sections.

Joints and Splices

Riveted and bolted joints are weakened by not providing proper edge distance. An edge distance of 2d (two times hole diameter) plus .06 in. is desirable, and provides margin for manufacturing errors. Use at least 5d rivet spacing. The use of 4d has no margin for manufacturing errors. Keep the manufacturing shop in mind!! Too many joints are designed using many small rivets when fewer and larger rivets would be cheaper and stronger. Do not design for rivets to carry tension loads. Provide close inspection of drilled rivet holes. Rivet holes only transfer loads where the rivet and structure touch and out-of-round holes do not provide continuous contact. Also, blind rivets do not swell like bucked rivets and even bucked rivets will not fill all out-of-round holes.

Bolted Joints

Threads should not be in bearing. Providing the proper torque is important. Bolted joints should not separate at less than limit load. Shear nuts should be used for shear applications only. Pay attention to bolt and hole tolerances. Again, load is not transferred across a gap! Friction should not be used as a load transfer mechanism, especially in a vibration environments such as space vehicle launch and landings.

Computer Programs

Computer programs are not a substitute for good basic judgment. Final reactions should be checked for summations at all forces; for this principle still holds even in the high technology age. Plot results and look for discontinuities in loads and deflections. Estimate the answers and then see if the computer results appear correct. Use the computer primarily for calculation of internal loads, then use these loads to conduct a hand stress analysis. Very highly stressed areas have been overlooked because finite element models had been overly simplified in a complex stress field. If the total capacity of the program is too small to provide for close grids in highly stressed areas, use a refined model for small areas. The person providing the finite element model must also understand load paths and basic structural design. Just assuming a load path does not make it happen!

General

Avoid the philosophy of "If Part A fails, Part B can carry the load." Failure of one part may cause a suddenly applied impact load which fails Part B. Zippers are fine, but not in structural design. Watch out for structure that is not easily inspected. Buried flaws are dangerous. Pay attention to the reflected shape of structure under load. If possible, avoid introducing concentrated loads into flat plates. The transfer of loads by bending is inefficient and heavy. Shear transfer is more efficient.

B2. The intent of the following comments from other division personnel is to suggest engineering practices which will emphasize the attention to detail during the design of the structure. When a high margin/minimum testing approach is intentionally selected, NASA recommends that a visible effort which emphasizes minimum risk and maximum attention to the "as built" hardware be employed.

General provisions

Complex machined parts with sections deemed critical by the stress analyst should be avoided. Tapered machined parts, especially if cumbersome to inspect, should be avoided. Structural instabilities which possess little or no postbuckling strength should be factored to obtain margin for secondary deflections and imperfections. The composite structure allowables should conservatively allow for degradation due to moisture, temperature, and process variables. Special attention to joint details to avoid peeling due to joggles and secondary structural deflections is required. Detailed inspection specifications should be "called out" for critical joints and splices. In all cases, only qualified and proven materials processes should be considered.

Joints and fasteners

The use of 'fitting factors' and some fail safe design philosophy is recommended. Fasteners should (in general) be critical in bearing rather than shear. However, fasteners with a high margin in shear are preferable to reducing material thickness or increasing fastener diameter just to make the joint critical in shear. Bearing critical fasteners are often required to produce the fastener load distribution used in the margin of safety calculation. For joints involving multiple fasteners, fail safe considerations for at least loss of one fastener should be imposed. Fasteners which require preload should be designed with margin of the minimum preload. Spot welds and welds which carry primary and secondary bending should be avoided. All welds should be designed assuming that the visually detectable flaw was indeed undetected.

Inspection and quality

The importance of an extra inspection/quality cannot be overstated. All persons involved should be aware that the structure being fabricated is a 'high margin' structure. To avoid a lack of day-to-day commitment to quality, special inspection requirements and formal engineering audits of the 'as built hardware' have been used constructively. Test coupons of materials, welded joints and bonded joints are recommended. When readily and practically feasible, proof test to detail parts and assemblies is recommended.

Materials and manufacturing process

Many lessons have been painfully learned about this subject. Careful selection of high toughness, ductile metallic materials which are resistant to stress corrosion is imperative. NASA has acquired a wealth of data concerning the toxicity and contamination characteristics of a large class of non-metallic materials. A design commitment to use these materials is recommended. The use of simple proven manufacturing processes is especially important when designing a 'high margin' structure. Explanatory supplement 'called out' on the drawing is recommended for any difficult assembly or manufacturing skills. Regular engineering liaison and 'hands-on' participation of the design engineering team should be mandatory.

Math model vs. as released drawings

Finite element modeling is the normal method of idealization and internal loads analysis. JSC insists that stress analysis be performed and tracked at the detail part level. This insures a check and balance on the finite element model and the stress distributions visualized and treated by the element selection. The use of element stresses directly from the output of the model requires serious review in most cases. Load transformation matrices are useful to isolate critical design conditions but are not necessarily a sufficient basis for computing the margin-of-safety.